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MAGNET ASSEMBLY FOR PLASMA CONTAINMENT

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MAGNET ASSEMBLY FOR PLASMA CONTAINMENT

BACKGROUND

An aspect of the present invention relates to a magnet assembly for a plasma process chamber.

In the fabrication of integrated circuits (ICs) and displays, a number of processes are performed on a substrate in a plasma process chamber, including the deposition and etching of layers on the substrate. Typically, the process chamber comprises a substrate support, a gas distributor, a gas energizer to form a plasma from gas, and a gas exhaust. In such chamber, a magnet assembly can also be used to generate a magnetic field about a substrate processing zone in the chamber, to for example, limit the passage of charged plasma species into an exhaust port that is part of the gas exhaust, or to control the distribution or movement of plasma species across the substrate surface. The magnet assembly is typically positioned about the chamber, for example, on a wall around the substrate support such as an external chamber wall or liner.

One type of magnet assembly comprises a housing holding a number of magnets, as described in commonly assigned U.S. patent publication no. US-2003-0192646-A, filing on 04/12/2002, entitled "Plasma Processing Chamber Having Magnet assembly and Method," which is incorporated herein by reference in its entirety. The housing is U-shaped to fit around a number of magnets, and is sealed by a cover plate that is welded along the open edges of the U-shaped housing. However, such magnet assemblies can be unreliable during operation. The weld seam of the housing often develops microcracks or holes with thermal cycling in the chamber, and the plasma in the chamber permeates through these holes and cracks to degrade the housing and magnets. This can have undesirable effects on the substrate being processed and the ability of the magnet assembly to contain the plasma.

Magnet assembly housings sealed by a cover plate can also be difficult to fabricate or assemble. Welding the cover plate typically involves subjecting the magnet assembly contained in the housing to high temperatures that can demagnetize or thermally degrade the magnets. It is also difficult to maintain the magnets aligned in

the housing while the cover plate is being welded on to the housing. Often, some of the magnets become misaligned during assembly and this results in the magnet assembly providing an undesirable magnetic field distribution.

Furthermore, when the assembled housing is subjected to an anodizing treatment to form a protective anodization layer on the housing, the anodizing treatment material can permeate thorough any fine microcracks or holes in the weld seam to enter into the housing. The magnets can be eroded or otherwise degraded by the anodization treatment material. Also, during chamber processing, the trapped anodization material can vaporize to outgas into the vacuum environment of the chamber, affecting the substrate process.

Thus, it is desirable to have a magnet assembly that is more resistant to plasma erosion. It is further desirable to have a magnet assembly that allows easier assembly and alignment of the magnets in the housing without damaging their magnetic properties.

SUMMARY

A magnet assembly for a plasma process chamber comprises a hollow collar having a cross-section that substantially continuous and is absent seams. The hollow collar also has an open end face and a cap to seal the open end face. A plurality of magnets are in the hollow collar, the magnets being insertable through the open end face of the collar.

The magnet assembly can be used in a plasma process chamber. The chamber comprises a substrate support, a gas supply to provide process gas, a gas energizer to energize the process gas, and an exhaust to exhaust the process gas. The magnet assembly can be snap fitted onto a wall of the chamber, such as a liner or external wall, and can also be shaped to fit into a groove in the chamber wall.

A method of refurbishing the wall comprises removing the magnet assembly from the wall, cleaning a surface of the wall, and fitting the same or another magnet assembly on the wall.

DESCRIPTION

A plasma processing chamber **100**, an exemplary illustration of which is shown in Figure 1, may be used to conduct a process in which material is deposited on or etched from a substrate **104**. An example of a commercially available plasma processing chamber is a dielectric etch chamber, such a Dielectric Etch eMax Centura™ system, commercially available from Applied Materials Inc., Santa Clara, California. The particular embodiment of the process chamber **100** shown herein, which is suitable for processing of substrates **104** such as semiconductor wafers, is provided only to illustrate the invention, and should not be used to limit the scope of the invention. Other process chambers capable of energizing a process gas, for example a DPS™ type chamber, also available from Applied Materials Inc., can also be used.

Generally, the chamber **100** comprises a substrate support **108** having a surface to support the substrate **104** in a process zone **112** of the chamber **100**. The substrate **104** is held in place by the substrate support **108**, which may be a mechanical or electrostatic chuck having a receiving surface with grooves (not shown) in which a coolant gas, such as helium, flows to control the temperature of the substrate **104**. . One or more walls **115** can surround the substrate support **108**. For example, the walls **115** can include a quartz dielectric ring **116** about the substrate **104** to protect the support **108** from the plasma. The walls **115** can also include liners **176**, **180**, as described below. The walls **115** can further include external walls, such as the ceiling **120** or side walls **124**. A substrate transfer port **128** in the side wall **124** can be provided to allow the substrate **104** to be transferred into and out of the chamber **100**.

To perform a process on the substrate **104**, the process chamber **100** is evacuated to a process pressure, and the substrate **104** is transferred to the substrate support **108** from a load lock transfer chamber (not shown), which is also at vacuum. The chamber **100** comprises a gas supply **132** to supply a process gas, which may be a single gas or a mixture of gases, to the chamber **100**. The process gas is introduced into the chamber **100** through a gas distributor **144** of a gas supply **132** comprising one or more gas lines **140** that connect a process gas source **136** to an inlet manifold **148** of the gas distributor **144** that conveys process gas through apertures **152** into the process zone **112**. The gas distributor **144** may comprise a showerhead plate that is located above the substrate **104** and is made from a dielectric material. A gas exhaust

166 is provided to exhaust spent process gas and etchant byproducts from the chamber **100**. The gas exhaust **166** comprise an exhaust port **117** about the chamber **100**, and can also include a vacuum pump **168** to pump the gas out of the chamber **100**. A throttle valve **172** is provided in the exhaust port **117** for controlling the pressure in the chamber **100** by regulating the flow of the gas between the process zone **112** and the vacuum pump **168**.

The chamber **100** further comprises a gas energizer **156** to energize the process gas to process the substrate **104**. Typically, the gas energizer **156** couples an electric field to the process gas in the process zone **112** to energize the process gas (i) inductively by applying an RF current to an inductor coil (not shown) encircling the process chamber **100**, (ii) capacitively by applying an RF current to a cathode electrode **160** and an anode electrode **164**, such as the side wall **124** (as shown), or (iii) both inductively and capacitively. In the version shown, the gas energizer **156** comprises an RF power supply (not shown) to apply power to anode and cathode electrodes **164**, **160**. In reactive ion etching (RIE) processes, the gas energizer **156** typically energizes the process gas by capacitively coupling an RF voltage from the power supply to the cathode electrode **160** at a power level of from about 100 to about 2000 Watts, and by electrically grounding the anode electrode. Alternatively, an RF current at a power level of from about 750 Watts to about 2000 Watts can be applied to an inductor coil (not shown) to inductively couple energy into the process chamber **100** to energize the process gas in the process zone **112**. The frequency of the RF current applied to the process electrodes **164**, **160** or inductor coil is typically from about 50 kHz to about 60 MHz, such as about 13.56 MHz.

The plasma or energized process gas may be enhanced using electron cyclotron resonance or magnetically enhanced reactors, in which a magnetic field generator, such as electromagnetic coils **184**, are used to apply a magnetic field to the plasma in the process zone **112** to increase the density and uniformity of the energized process gas. The magnetic field may comprise a rotating magnetic field with the axis of the field rotating parallel to the plane of the substrate **104**, as described in U.S. Patent No. 4,842,683, issued June 27, 1989, which is incorporated herein by reference in its entirety. The magnetic field in the process chamber **100** may be sufficiently strong to enhance the plasma. For example, the magnetic field as measured on the substrate

104 may be less than about 500 Gauss, and more typically from about 10 to about 100 Gauss.

The plasma processing chamber **100** may also have a chamber liner **176** adjacent to the anode **164** and a cathode liner **180** adjacent to the cathode **160** to shield the anode **164** and cathode **160** from the plasma. The liners **176, 180** facilitate a short down time, because they can be removed from the processing chamber **100** to be wet cleaned outside the chamber **100**. Additionally, the liners **176, 180** may be adapted to adjust a DC bias between the anode **164** and the cathode **160**. For example, the liners **176, 180** may be of a surface area, thickness, or placement which can be selected to obtain a suitable DC bias. One or more of the liners **176, 180** may comprise a dielectric material to electrically insulate the anode **164** and cathode **160** from the plasma. The liners **176, 180** can also be concentric to one another. In the embodiment shown, one or more electrically conductive parts of the chamber walls **120, 124** serve as the anode **164**. The anode shield **176** is an inwardly-facing lining at the top and sides of the chamber **100**. The cathode liner **180** lines the sides of the cathode **160**. In one version, the liners **176**, **180** comprise annular protrusions (not shown) that function in combination as an exhaust baffle. For example, the annular protrusions may form an S-shaped channel therebetween to break the flow of gas to the gas exhaust **166**.

The chamber **100** further comprises a magnet assembly **200** that serves to control a flow path or distribution of plasma species. The magnet assembly **200** is located about the section of plasma or process zone in the chamber **100** for which is desirable to control the distribution of plasma ions. For example, in one version, the magnet assembly **200** may generate a magnetic field that increases in strength along a path from the chamber center to the outwardly positioned gas exhaust **166** to impede or altogether prevent the plasma from extending into the gas exhaust **166**. In this version, the chamber **100** comprises two magnetic assemblies **200**, one assembly **200** attached to the chamber liner **176** and another attached to the cathode liner **180**, at a location on the liners **176, 180** about the flow path to the gas exhaust **166**.

The magnet assembly **200**, as illustrated in Figure 2, comprises a hollow collar **204** capable of holding a plurality of magnets **208**. The hollow collar **204** can form a ring segment that encircles the chamber **100**, the ring segment being generally circular and conforming to the circular wall of the chamber **100**. Thus, the magnet

assembly **200** can comprise a single collar **204** that is split ring **252** having a single split **253** along its circumference. The collar **204** can also be a semi-circle ring segment **254a,b** such that the two ring segments cooperate to form a substantially continuous ring about the chamber. The collar **204** can also have other shapes generally conforming to the structure about which the collar **204** is attached or supported. For example, if the chamber **100** has rectangular walls, the collar **204** is also rectangular in shape. Each collar **204** holds a plurality of pre-positioned magnets **208** abutting one another to generate a predefined annular magnetic field in the chamber **100**, and also to protect the magnets from the plasma processing environment. In one version, the collar **204** of the magnet assembly **200** is shaped to surround a substrate support **108** that is sized to fit within an inner radius of the magnet assembly **200**. In another version, the collar **204** can also be contained in or around the substrate support **108** or the exhaust port **117**.

The hollow collar **204** has a continuous external surface **212** with a cross-section that is absent welds or seems. The welds or seems are subject to corrosion and etching when exposed to the plasma environment, which may lead to a breach in the collar **204** and exposure of the magnets **208** to the plasma. The unbroken cross-section protects the magnets **208** enclosed by the collar **204** from the plasma. The unbroken cross-section improves the reliability of the magnet assembly **200** by eliminating the presence of pores or microcracks that often occur in weld seams. In comparision to conventional collars, the present collar **204** provides better plasma protection, more robust operation and lower fabrication costs. This improvement in performance provides less chamber downtime and higher process throughput yields

The hollow collar **204** is shaped with internal surfaces **216** that cooperate to conform to the shape of the magnets **208** so that the magnets are held therein with minimal movement, as illustrated in Figure 3. The internal surfaces **216** of the collar **204** are collectively shaped to accommodate the plurality of magnets **208**. In one version, the internal surfaces **216** form a hollow cross-section having a rectangular profile. This is advantageous when the plurality of magnets **208** in the assembly **200** are organized into a set of magnets arranged abutting one another in an annular configuration around the collar **204** to generate an annular magnetic field about the chamber.

In one version, the internal surfaces **216** of the hollow cross-section comprise a separator wall **220**. The separator wall **220** may be a protrusion from one of the internal surface **216** of the hollow cross-section. A separator wall **220** is advantageous when the plurality of magnets **208** in the magnet assembly **200** are organized into two parallel sets of magnets arranged annularly around the collar **204**. In this version, the separator wall **220** is located between the two parallel sets of magnets and separates the parallel magnets by a predefined separation distance. A suitable separator wall thickness is from about 0.05 inches (1.3 mm) to about 0.500 inches (12.7 mm).

The magnet assembly **200** is attached to receiving surfaces **224** within the plasma processing chamber **100**. For example, in one version, the magnet assembly **200** is attached to a wall **115** such as a chamber liner **176** or cathode liner **180**. In this version, the magnet assembly **200** can also be snap fitted onto the wall **115** by sizing the diameter of each collar **204** smaller than the diameter of the wall **115.** The snap fitted collar **204** is shaped and sized to be sufficiently flexible to allow the collar **204** to expand diametrically when an operator pulls on the ends of the collar **204**. The expanded collar **204** is then releasably applied to the wall **115**, whereupon it reverts to its original diameter and securely grips the circumference of the wall **115.** The external surface **212** of the collar **204** can also have a profile that is shaped to mate to a corresponding groove **228** in the surface of a wall **115**, such as the chamber liner **176** or cathode liner **180**. For example, the external surface **212** of the magnet assembly **200** can form a rectangular cross-sectional profile that mates to a corresponding rectangular groove **228** in the chamber liner **176** or cathode liner **180**.

The external surface **212** of the collar **204** can also have a key **232** to couple to a corresponding slot **236** on the receiving surface **224** of the chamber **100**, such as a slot **236** located on a receiving surface **224** of the groove **228** in the chamber liner **176** or cathode liner **180**. The key **232** aids in the proper alignment of the assembly **200** to the receiving surface **224**. For example, the key **232** aids in the alignment of the assembly **200** to the liner **176**, **180** in a certain preferred orientation. In one version, the plurality of magnets **208** may be arranged within the assembly **200** to have a certain polarity relative to the location of the key **232**. Using the known relationship of the polarity to the key, the assembly **200** can then be attached to the

liner **176**, **180** with the polarity of the plurality of magnets **208** maintained in a desirable relationship relative to the chamber **100**.

In one version, the collar **204** comprises a substantially continuous annular structure with a gap **240** at a split along its circumference. The gap **240** is a predefined distance between the adjacent split ends of the collar **204**. For example, the gap can extend a predefined number of degrees of rotation about the center of the radius of the collar **204**. In one version, once attached to the receiving surface **224** of the chamber **100**, the gap **240** extends through an angle of about 1 to about 5 degrees, to avoid interference during installation. The gap **240** facilitates attachment of the magnet assembly **200** to the receiving surface **224** of the chamber **100**, such as the groove **228** in the chamber and cathode liners **176**, **180**. The collar **204** can be diametrically expanded by widening the gap **240**, allowing relatively flexible manipulation in space of the magnet assembly **200** about the liners **176**, **180**. This diametric expansion allows snap fitting of the collar **204** to the groove **228** in the liners **176**, **180**, including the alignment of the key **232** to the corresponding slot **236** and the attachment of the retaining ring **252**. Thus, the gap **240** is sized so that the collar **204** can expand a sufficient amount to be snap fitted onto a wall of the process chamber **100**.

An open end face **244** to the interior volume of the collar **204** is located about the gap **240**. In one version, both sides of the gap **240** are faced by open end faces **244** to the interior of the collar **204**. The open end faces **244** are used to insert a plurality of magnets **208** into the collar **204**. The open end faces **244** into the interior of the collar **204** are sized to accept the magnets **208** and the outline of the open end faces **244** can correspond to the profile formed by the internal surfaces **216** of the hollow cross-section.

The magnet assembly **200** further comprises a cap **248** to seal the open end face **244**. There are as many caps **248** as open end faces **244**. The caps **248** seal the open end faces **244** to protect the plurality of magnets **208** within the collar **204** from exposure to the plasma environment. The caps are composed of a material resistant to the plasma environment. In one version, the caps are composed of a material such as aluminum or steel. The caps **248** are attached to the open end faces **244** using an epoxy suitable to withstand the plasma enviroment. In one version, the

epoxy used to seal the caps **248** into the open end face **244** can be HySol Epoxy 1C from Henkel Loctite Corporation, located in Rocky Hill, CT, but other, equivalent epoxies can also be used.

The magnet assembly **200** may further comprise a retaining ring **252** to retain the assembly **200** within the groove **228** in the liner **176**, **180**. The retaining ring **252** fits between an external surface **212** of the collar **204** and a receiving surface **224** of the groove **228** in the liner **176**, **180**. The groove **228** in the liner **176**, **180** can be sized slightly larger than the collar **204** to allow ease of placement of the collar **204** within the groove **228**. The retaining ring **252** can be attached to take up the slack between the hollow collar **204** and the groove **228**. The retaining ring **252** is relatively easier to handle than the hollow collar **204** containing the magnets **208**, and thus, facilitates attachment of the magnet assembly **200** to the receiving surface **224**.

The magnets **208** are typically permanent magnets that, for example, comprise a ferromagnetic material, such as a rare earth metal. The rare earth metal is able to generate a strong magnetic field relative to the amount used. For example, the magnets **208** may comprise neodymium-iron-boride or samarium-cobalt. The magnets are sized to be insertable through the open end face **244** of the collar **204**. Each individual magnet **208** has a magnetic axis aligned with its north and south poles, and a polarity direction running from the south to north pole. The magnets **208** may be coated with an adhesive prior to their insertion and assembly into the magnet assembly **200**. The adhesive keeps the magnets **208** from moving or shifting inside the magnet assembly **200** in response to electromagnetic fields that may be present in the processing chamber **100**.

The magnet assembly **200** provides an arrangement of a plurality of magnets **208** into an annular configuration about a chamber wall **115** or other chamber or component structure, to generate a magnetic field in the chamber **100**. In one embodiment, the magnet assembly **200** attached to the chamber liner **176** contains a plurality of magnets **208** arranged annularly such that the polarity of each magnet **208** is aligned to a central axis of the chamber **100** that runs vertically through the center of the chamber from the top to the bottom of the chamber **100**. In this version, the

plurality of magnets **208** are positioned in the collar **204** such that their south poles are directed upwardly and the north poles are directed downwardly.

In another embodiment, the magnet assembly **200** attached to the cathode liner **180** contains two sets of magnets **208** that are parallel to each other. Within each set, the magnets **208** are arranged in an annular configuration in the collar **204** such that the magnetic axis or polarity of each individual magnet **208** is oriented perpendicular to the wall of the chamber **110** or horizontal relative to the central axis of the chamber **100**. This arrangement comprises a first upper set **260** of magnets **208** and a second lower set **264** of magnets **208**. The magnetic axes or polarity of the first set **260** points from the center of the chamber **100** outward along a radial direction relative to a circular chamber **100**. The magnetic axis or polarity of the second set **264** points in the opposite direction, pointing from the outer portion of the chamber **100** into the center of the chamber **100**. The above polarity configurations are only exemplary, however, and other polarity configurations are possible and fall within the spirit of the present invention.

The magnet assembly **200** may further comprise one or more pole pieces **256** to separate magnets **208** arranged in parallel within the collar **204**. A suitable pole piece **256** is composed of ferromagnetic material. The addition of a pole piece **256** between parallel magnets **208** may create a specific magnetic field configuration. For example, in Figure 3, the addition of a pole piece **256** is positioned to south poles of the first set **260** of magnets **208** to the north poles of a second set **264** of magnets **208** to create a circular horse-shoe magnet having both north and south poles facing the same direction.

The collar **204** may be composed of a material resistant to degradation in a plasma environment. In one version, the collar **204** is composed of aluminum. In another version, the collar **204** may be composed of stainless steel. The collar **204** may be manufactured using a number of methods, including extrusion, casting, machining and forging.

After extended exposure to the plasma environment, the walls **115** in the chamber **100** may be cleaned and refurbished. In the refurbishment process, the magnet assembly **200** is removed from a chamber wall **115**, such as a liner **176, 180,** to

allow cleaning of the wall. The wall **115** is then cleaned, for example, by a cleaning solution employing an acid or base, the cleaning process being conducted outside the chamber **100**; or they may also be cleaned by a plasma dry cleaning process conducted in the chamber **100**. The same magnet assembly **200** or a new one is then fitted back onto the wall and the wall **115** is reinserted into the chamber **100**. In addition, the hollow collar **204** also allows a new set of magnets **208** to be substituted, or the magnets **208** can be removed for use in another hollow collar **204**. In the latter method, the cap seal of the collar **204** is broken and the cap **248** is opened. The magnets **208** are removed from the open end face in the hollow collar **204**. The magnets **208** may be cleaned and reused, and the hollow collar **204** itself, can also be cleaned and re-used. Alternatively, a plurality of new magnets **208** are also be re-inserted through the open end face **244** of the hollow collar **204**. The new magnets **208** may be cleaned versions of the used magnets or other magnets. The open end face **244** is then sealed with a second cap **248** to form another magnet assembly **200**. Thus, the present magnet assembly **200** advantageously allows reuse or replacement of the magnets **208** contained therein. It also allows replacement of the magnet assembly **200** as a complete assembly within the wall **115.**

Although the present invention has been described in considerable detail with regard to certain preferred versions thereof, other versions are possible. For example, the magnet assembly **200** can be used for other chambers or for other processing applications, as would be apparent to one of ordinary skill in the art. Alternative geometrical shapes and configurations may also be substituted for the illustrative versions of the collar **204** or arrangements of the magnets **208**, for example, the magnets **208** may be disc or pole shaped, and the collar **204** can be shaped to conform to the disc or pole shaped magnets, respectively. Therefore, the appended claims should not be limited to the description of the preferred versions contained herein.